will soon be in the coming century, a more wonderful period of Evolutionary Science will then open, than even that which has made this 19th Century conspicuous. And when these physiological processes do thus become the object of enthusiastic research, at that moment will the rôle of "mind" begin duly, and necessarily to receive preponderating attention. This will happen the same, whether Parallelism remain the popular doctrine or not. *Conduct* is sure to be recognized, in time, as the major region of Physiological Biology; and "mind" is the chief source of conduct, whether the word imply " molecular activities or " psychic force."

This, then, in one word, is the summary of all our conclusions. Mind would not be mind save for its marvelous complexity. The basis of this cmplexity is the variety of its sensory elements. These elements, or their physical equivalents, then, must be major factors of animal evolution; they must explain the origin of mind; and they must play in Biology and Physiology all the part that mind unquestionably plays. To neglect them hereafter, either in Biology or in Psychology, is to neglect a major factor, and probably *the* major factor of both Sciences.

FOSSILS AND FOSSILIZATION.

By L. P. Gratacap.

III.

(*Continued from Vol. XXX, p. 1003.*)

Two very remarkable and instructive deposits of vertebrate remains which illustrate their placement, sepulture, and mineralization, are represented in the tertiary beds of the Niobrara River in Nebraska, the lacustrine basins of Wyoming, in the United States, and the fluviatile plains of Argentina and Uruguay in South America formed by the water-ways which preceded and defined the present Parana, Paraguay, Uruguay and La Plata Rivers. In South America the Parana, Paraguay and Uruguay Rivers carry down vast amounts of sand,

clay and detritus from the eroded mountain chains of Brazil. And this is due to the fact, as pointed out by J. Ball (Notes of a Naturalist) that a continuous and heavy rainfall in Brazil not only aids in the process of disintegration of the rock, but supplies the necessary vehicle for transporting it away. The annual rainfall in Brazil varies from 100 to 130 inches, and as its eastern seaboard is its oldest surface, this region has been "subjected throughout vast periods of geological time to the utmost force of disintegrating agencies, applied to a rock very liable to yield to them, and where, without reckoning the large proportion which must have been carried by rivers to the sea, we see such vast deposits of the disintegrated materials formed out of the same matrix." The lofty maritime ranges of Brazil have been reduced by this constant withdrawal of their materials, and the predecessor of the present river system which had its inception in those early ages afforded the conduits by which the vast quantity of detrital matter was borne down over the broad pampas and plains of Argentina and Uruguay. We may conceive that this weathering and deposition were carried on with greater energy at a time when meteorological disturbances were more violent, and when these same streams, represented in that distant time by much shorter rivers, had a steeper slope, ran more swiftly, and possessed greater erosive or tearing and sweeping power. This discharge of abraded matter has built up the wide level country which now constitutes the flat lands of Argentina and Uruguay, whose extensive pampas arose through this sedimentation continued through ages of this current of abrasion. In turn the rivers ploughing new channels through the vast accumulations over which they were now compelled to make their way, continually added to the outskirts of the new formation, and with every increment extended their own banks, and gradually assumed their present proportions and their present course. For, to use the language of Prof. Ball, "it cannot be doubted that the finer constituents carried down by the Parana and its tributary, the Paraguay, from the same original home, have largely contributed to the formation of the Argentine pampas, and Paraguay, including the northern portion of the Gran-

Chaco. Borings and chemical analysis of the soil may hereafter give us reliable data; but in the meantime we may safely reckon that an area of 200,000 square miles has been mainly formed from the materials derived from the ancient mountains."

In the west, in Wyoming, Nebraska, and Montana, there existed in tertiary times large fresh-water lakes,[1] the successors to the wide cretaceous seas which before that era swept over the axis of the scarcely emergent Rocky Mountains. Into them, from the erosion of the non-resisting strata of their margins and encircling ridges—an erosion caused by heavy rainfalls which appear at times to have acquired the strength and permanency of the precipitation in the tropical rain areas—was washed enormous quantities of shore sand and continental mud and silt. These contributions of earthy matter in conjunction with the organic testaceous life of the lakes were finally consolidated into deposits of shales, marls and earthy limestones. Into the wide bosom of these contiguous and more or less connected sheets of inland water was also gathered the remains of a remarkable fauna, wherein, as Dr. Newberry remarks, we have the proof "that during unnumbered ages this portion of the continent exhibited a diversified and beautiful surface, which sustained a luxuriant growth of vegetation and an amount of animal life far in excess of what it has done in modern times." The fossilization of these mammals (Carnivora, Insectivora, Ruminantia, Pachyderma, Rodentia) is a matter of considerable interest. They must have been introduced into the lakes by sudden meteorological emergencies when their own capture and imprisonment in these seas was synchronous with violent terrestrial denudation by which they were safely entombed. Their own character and that of the associated flora forbid the supposition, advanced by Lyell and apparently applied by Hayden, as to their having fallen into the waters through breaking ice, over whose precarious sur-

[1] It must be remembered, however, as Dr. Hayden indicated, that "the lowest beds of the Tertiary exhibit a somewhat brackish or estuarine character, and a few fossils (*Ostrea subtrigonalis*) are found which are peculiar to such waters." Preface to Leidy's Extinct Mammalian Fauna.

face they were passing. The year was then one of sub-tropical mildness and warmth. Their excellent preservation in many instances, as well as the number and completeness of their skeletons, prove that their fossilization resulted from a sudden calamity and rapidly ensuing sepulture. It seems most likely that the floors of those ancient lakes were themselves abysses of mud, a soft calcareous and argillaceous silt into which the great mammals sank when dead, or if caught in overwhelming floods were speedily enveloped in the accompanying torrents of earthy material. These remains have undergone a partial mineralization, and have been penetrated by the mineral matrix quite extensively. In examining the typical collection of mammalian fossils from the White River of Dakota, from which Dr. Leidy made many of his species, I have observed the process of fossilization. The marrow cores of the leg-bones of *Oreodon culbertsonii* Leidy are almost closed with chalcedony quartz and calcite. The brain cavities of the same animal are filled with an exact mould of marl which indicates the pasty consistency of the original substance in which the skull was placed. The remarkable series of similar moulds used by Prof. Marsh (Monograph of Dinocerata) to illustrate the growth and specialization of the animal brain have been formed in the same way, retaining with fidelity the furrows and rugose character of the interior surfaces of the skull.[2] The interparietal spaces of the lower jaws of *Hyracodon nebracensis* Leidy are also invaded by clay and mineral matter, so as to partially mineralize the contiguous bone. In the leg-cores of the same animal a cement of argillaceous limestone with separated grains of quartz and sometimes a solid stem of quartz filling the passages are noticeable. The bones of *Menodus proutii* Leidy are heavy from parietal petrifaction and replacement, and in some the cellular structure of the bone is saturated with chalcedony flakes and granules. It is quite certain that the geological changes which have effected the elevation of these tertiary lakes and made them dry basins,

[2] These brain moulds might not be strictly considered fossils, but they come within the application of our definition as an "indication of life" in the same way as casts of shells.

bringing with them a train of mineralogical accidents as a necessary accompaniment in the percolation of mineral waters and the solidification of the natural cement which surrounds the fossils have contributed towards rendering these remains impenetrable. I do not know how the petrifaction of bone compares with the silification of wood, either as a process or in the time required, but it is certain that, in some instances, teeth have been completely changed into a mineral, as in the case of the saurian teeth found by Mr. C. M. Wheatley in a bone bed at Phœnixville, Pa. Here, to quote Mr. Wheatley's own words, "*the casts* only of the teeth remain, the substance of the tooth being converted into *dolomite*, but retaining the exact form of the tooth with the sulcations as distinct as in the original. Twenty teeth, of probably three or four genera of Saurians, *all converted into dolomite* occur on a piece of sandstone six by three inches."

Bischof, quoting the results of Marcel de Serres and L. Figuier, says that the chemical changes involved in the petrifaction of bones consist principally in a diminishment of the organic matter, in an entire disappearance of the phosphoric acid, and in an increase of the carbonate of lime and iron oxide.

Again, Fremy found that the animal substance of bones—the so-called *ossein*—was decomposed by burial and replaced by various incrusting minerals, namely, silica, sulphate of lime, fluoride of lime, and especially carbonate of lime.

Dr. Mantell has made some interesting observations on the mineralization of bones. He remarks (Petrifactions and their Teachings) of the bones of reptiles that "the osseous carapaces and plastrons of the turtles, and the bones and teeth of the crocodiles and lizards, are almost without exception heavy, and of various shades of brown or umber, from the permeation of their structures by solutions of carbonates or oxides of iron." Mantell refers to the curious appearance of bones imbedded in white limestone, which have become a blue-black from the combination of their phosphoric acid with iron, forming the blue phosphate of iron (vivianite), while in other cases the open surfaces and cells are infiltrated with calc-spar or refulgent with a golden frost of iron pyrites.

It is rare to find fossil bones silicified, and this replacement so common in vegetable or invertebrate remains is very uncommon. The bones of vertebrates are often found distorted from having undergone softening from their partial maceration in water, and become almost unrecognizable upon their extraction.

"The Maidstone Iguanodon," says Mantell, "is a striking example of this kind; in the entire series of bones exposed, there is scarcely one that is not more or less altered by compression. The humerus and thigh-bones especially are completely distorted; the vertebrate pressed almost flat, or squeezed into abnormal shapes, etc." Bones of the Moa, taken out at North Island, New Zealand, were of the consistency of putty, and could be broken or kneaded almost like columns of clay, but hardened upon exposure and drying.

In this connection, relative to the accumulation of bone deposits in the past, some observations of the recent African traveller, J. W. Gregory, are of vital interest. He says (The Great Rift Valley, J. W. Gregory, p. 268) "here and there around a water hole we found acres of ground white with the bones of rhinoceros and zebra, gazelle and antelope, jackal and hyena, and among them we once observed the remains of a lion. All the bones of the skeletons were there, and they were fresh and ungnawed. The explanation is simple. The year before there had been a drought, which had cleared both game and people from the district. Those which did not migrate crowded round the dwindling pools and fought for the last drop of water. These accumulations of bones were therefore due to a drought and not to a deluge."

The fossilized remains of marine vertebrates are not uncommon, and in the cretaceous beds of Wyoming they have been preserved with remarkable completeness, eliciting the remark from Prof. Marsh that "he noticed the skeletons of six of those mighty swimming lizards—the mosasaurs—each eighty feet in length, in sight at one time."

The fish beds at Twin Creek, Wyoming, the fish remains in Ohio, including the great Dinicthys, those at Sunderland, Mass., together with numerous indications of marine creatures

in the Cretaceous of New Jersey and the phosphate deposits of the Ashley River, S. C., seem to show that somewhat more favorable conditions for their preservation existed in these earlier times than at present, when bones appear to become quickly destroyed in the ocean, and only the most refractory substances, as enamel and very dense bone, resist the agencies of solution. It seems altogether likely that the sedimentation must, at least at seasons or periods, have been rapid and considerable; that vast volumes of calcareous mud discharged into the cretaceous seas entrapped fish and reptile within the unchanging films and sheets of earthy matter. The wonderfully preserved fish of the eocene in the Green River beds, exhibit instances of almost complete immobility, as if no motion had disturbed the fish since its death, no tide or current, and that it was quickly covered over by sediment. The fish and reptilian remains in Ohio, Illinois, Pennsylvania, Iowa and Missouri bear evidence of separation and rolling, the articulations being infrequently retained in place, the mouth parts and skulls alone cohering together, though these are more commonly dismembered, while in complete uniformity with the experience of to-day, in many cases, teeth and spines are the sole representatives of these ancient denizens of the sea. Mechanical conditions under which marine vertebrate remains have been entombed very naturally affects the nature of their preservation. The sandy, coarse shore deposits which prevailed in the Catskill period—our equivalent of the Old Red Sandstone of Europe—was unfavorable for the cohesion of the fish which were enclosed in it, and the action of shore waves and the agitation of the gravelly matrix broke them apart, and scattered over the shore surface the fragments of bones, scales and spines. On the other hand, the shallow sea basins wherein the Huron and Erie (now shown by Prof. Orton to be identical) shales were deposited, furnished a fine-grained impalpable carbonaceous silt in which occasionally the remains of the monstrous placoderm Dinicthys were entombed entire, and preserved with comparatively slight dislocation or injury. In the open sea of the Upper Helderberg and Carboniferous where conditions similar to our present seas

may have prevailed, little else than the hardest portions of the fish were preserved as the dermal tubercles, spines and armored heads, with an occasional jaw retaining its teeth. Even this slender survival of material compares favorably with the destructive activity of our seas, and may perhaps add weight to the opinion of Verrill and Smith that this destruction to-day can be only assigned to the depredations of small crustacea. It also lends some seriousness to suspicions that in these paleeozoic waters deposition was more rapid than at present. But in the fish layers of Boonton, N. J. and Sunderland, Mass., in the Triassic slates and in the thinly fissile lime shale of Twin Creek, Wyoming, we find an extensive placement of fish skeletons and bodies which are usually quite perfect in outline and which must have been deposited almost simultaneously by some sudden catastrophe, and also very rapidly sealed within fresh sediment, in which they remained undisturbed by the motion of the water, and protected against change by the overlying films of calcareous mud. Dr. Newberry has suggested that in the case of the triassic fish their death was connected with the irruption of hot waters produced by the intrusion of the igneous trap rocks through the floor of the triassic sea. The similar beds at Weehawken, N. J., show that the fish have undergone considerable maceration and distortion, and the subsequent breaking of these slates have helped to obliterate the organic remains. The Twin Creek fish bed is a compilation of very thin sheets of flaky limestone with clay, between whose slightly undulating surfaces runs a waving black film, the section of a slab presenting a delicately lined face like a paper pencilled with parallel tracings. Here the fish lie with very slight dislocation appearing; to use Dr. Leidy's words, "as if whole shoals had been suddenly enshrined for the contemplation of future ages." It would seem as if an innumerable series of overflows, each carrying with it floculent carbonaceous matter, had left a deposit of carbonate of lime from suspended particles over the fish, and, as each overflow receded, these fine particles followed the absorbed water and remained upon the surface in a veil of black sediment. It may be that a sudden irruption of water carrying

suspended mud may have overwhelmed these fish, and this water-burst may have been attendant upon other circumstances by which the fish were frightened into shoals and exposed to a common death. The carbonaceous films may also be due to the penetration of oil between the laminæ of limestone, the oil arising from the decomposition of fish.

Some of the bone beds of Ohio present a mass of ground plates, broken teeth and crushed spines, which have become cemented together by carbonate of lime into a breccia of organic fragments. They represent, according to Dr. Newberry, a deposit in deep water of the excrements of larger fish whose digestive vigor has failed to entirely destroy the harder parts of their prey. It is not necessary to assume that these remains were buried very quickly, as their own strength and hardness would resist erosion, solution and the destructive power of animal feeders, though the circumstances attending its deposit must have been peculiar. A fragmentary layer of such a character accumulated in deep water—this conclusion Prof. Newberry believes is warranted on account of the absence of shore stones, gravel, pond wash, etc.—and not dispersed by the currents, and quite destitute of all other fossils than fish debris, is an anomaly which Prof. Newberry explains by this assumption: "It has seemed to me not impossible that this fish bed was, for the most part, made up of excrementitious matter, and that it represents the hard and indigestible parts of fishes which have served as food for other and larger kinds. On this supposition the fragmentary and worn appearance of the bones would be attributable to the crushing, maceration and partial digestion which they have suffered. If this is the true history of the deposits, it accumulated in some nook or bay, perhaps bordering a coral reef, where large and small fishes congregated, age after age, until their kjokkenmöddings formed a sheet some inches in thickness over all the sea-bottom."

It may, however, be said that the strongly bituminous or oil odor in this rock elicited upon striking it, shows that it did not represent solely the excrements of fish, but received very probably the occasional contribution of the bodies of living

members of the surrounding marine fauna. In this connection the important observation recorded in Lyell's Principles (Vol. II, p. 583), that upon the north coast of Ireland—the Rockhall Bank—"a bed of fish bones was observed extending for two miles along the bottom of the sea in ten and ninety fathoms of water," is of interest. Lyell, in the same place, also speaks of fish bones occurring in extraordinary profusion eastward of the Faroe Islands. This "bone bed" was three miles and a half in length and forty-five fathoms under water, and contained a few shells intermingled with the bones.

In the cranial plates of *Acanthaspis pustulosus*, one of the fishes of the Devonian of Ohio, the space between the outer hard bony walls are filled with carbonate of lime which has infiltrated and consolidated the intra-mural cellular tissue, while the clavicle of *Onychodus sigmoides* presents internally a granulated area of carbonate of lime similarly formed and Prof. Claypole speaks of the second layer of the shield of his placoderm fish from the Upper Silurian of Pennsylvania as having its cells "filled with infiltrated calcareous matter which, under the action of the weather, is dissolved out, leaving an exceedingly brittle cellular mass to represent the original shield". These bones probably retain their phosphate of lime, since fish bones and teeth in the Old Red Sandstone in Lievland (?) according to Bischoff, have lost but very little of the original percentage of this salt.

It must, however, be remembered that normal calcium phosphate is soluble in ammoniacal salts, sodium nitrate, common salt and other salts; that its abstraction from buried bone may be quite rapid, and the cavities left by its absorption may become filled with mineral matter. An exchange may be effected between carbonates of alkalies and the phosphates in bone by which carbonate of lime remains and the phosphoric acid is removed, and solution may be effected by aqueous carbonic acid alone. The turtles of the Miocene of Nebraska, which are so numerous, are represented by their joined carapaces and plastrons, and these are filled with the porous marl or earthy limestone of the White River beds. The bone of these parts presents a finely reticulated structure, and

through its minute passages a ferruginous infiltration appears, giving it a speckled surface. It seems more than likely that much of the original phosphate has disappeared, and that carbonate of lime with argillaceous admixture composes the present skeleton.

The fish of the Twin Creek, Wyoming basin have each been immersed in the products of its own decomposition. Their bones seem to be, in many instances, covered by an integument formed from the dried and mineralized skin and scales of the living fish, while the oily elements arising from their dry distillation or decomposition have impregnated the bones, converting them to a dark honey-brown substance somewhat laminar in structure, in places, elsewhere irregularly cubical, and soft and brittle. The fish in the triassic shales present ichthic outlines made up of rhomboidal scales. These scales, as is well-known, are essentially bone, very smooth, hard and lustrous, their shining and durable surface being formed of a substance allied to enamel and now called *ganoin.* This ganoin has undergone little or no change. The scales yield slowly to hydrochloric acid. The original cartilaginous or fleshy parts have probably aided preservation by forming oily products which bathed the fish, enclosed as it was in the shale, and upon dessication contributed their indestructible carbonaceous residues to its mass.

The cretaceous saurians entombed in the gypsiferous shales and limestones of Kansas have successfully escaped the action of decay, while the remains of sharks, predaceous fish, and tortoises are also found as fossils, but only in a partial phase, at least, of preservation. The bones of the fish, who were, according to Cope, related to the salmon, possess such a density and hardness that they are maintaïned as nuclei crowning knobs of shale, which stand in relief amidst the worn and denuded surfaces about them. This is quite remarkable, and seems to clash completely with what we know to-day of the preservation, or rather absence of preservation, of the bones of marine vertebrates. Prof. Marsh, in speaking of the specimens of cretaceous birds, remarks that "that they are all *mineralized* and in the same state of preservation as the bones of the extinct reptiles which occur with them in these deposits."

In the process of mineralization, which is the last phase of the entire process of fossilization, we may imagine that bones undergo contrasted changes, according to the varying circumstances of their position. Prof. Leidy has even observed in a letter to Dr. Holmes that fossilization, petrifaction or lapidification is no positive indication of the relative age of organic remains. The cabinet of the Academy of Natural Sciences of Philadelphia contains bones of the megalonyx and of the extinct peccary, that are entirely unchanged: not a particle of gelatine has been lost, nor a particle of mineral matter added, and, indeed, some of the bones of the former even have portions of articular cartilage and tendinous attachments well-preserved. On the other hand, bones of mammals from the Keuperkalk near Schweinfurt, Germany, yielded to Von Bibra scarcely a trace of phosphoric acid (Bischof); the principal constituent was clay. Bones exposed to saturation by water which may, or must, contain a very considerable quantity of mineral salts in solution, soon surrender their soluble elements and undergo a gradual reconstruction amounting, in some cases, to complete lithification. The phosphate and carbonate of lime may be replaced by silica, or the former may be expelled by reaction with alkaline carbonates, and the bone assume more and more entirely the composition of carbonate of lime.

The circumstances attendant upon the fossilization of invertebrates necessarily contrasts strongly with those observed in the fossilization of vertebrates. Invertebrates—corals, mollus, crustacea—are more usually the inhabitants of the salt waters, they are sedentary or somewhat limited in the range of their voluntary wanderings, their hard parts are almost entirely carbonate of lime, and at their death their shells or coverings are apt to be so situated as to secure more or less perfect preservation. The invertebrates which form the largest part of the fossil remains of the world are shore occupants, or, if removed from land, were living in comparatively shallow waters, waters certainly not exceeding 500 fathoms in depth. They lived either in the sandy flats or rocky barriers along the very margins of the ancient ocean and upon the oscillat-

ing edges of the continent, or in the impalpable sediment deposited further away from the shore, or gathered in estuarine inlets, or they formed the denizens of purer and deeper waters and became later, in the secular changes of the earth's crust, consolidated into limestone beds. This variation of position implied a greater or less likelihood of preservation as fossils.

Darwin has observed that along the west coast of South America " no record of several successive and peculiar marine faunas will probably be preserved to a distant age." And the reason he assigns is that as the coast of that continent is rising, " the littoral and sub-littoral deposits are continually worn away, as soon as they are brought up by the slow and gradual rising of the land within the grinding action of the coast-waves." The remains of animals so situated as to become exposed to the reassorting action and denudation of the shore currents and waves may suffer pulverization and dispersal, and those which are not soon covered by sediment may be dissolved or injured. Those farther away are entombed in the accumulation of sediment which falls down over the sea-floor more uninterruptedly at some distance from land where it is less agitated and shifted by the waves and currents. In the elevation of the ocean bottom and its gradual change to dry land the emergent surfaces would undergo considerable disturbance from the waves, and along these eroded edges the fossils would disappear by crushing and attrition. Yet Darwin's observation seems scarcely so important, when we consider that the same stratum continued outward upon the sloping bed of the ocean is for some time exempt from this wearing, and during that time the sediments produced by the destruction of its own emergent portions are constantly accumulating over it and rendering its own stability greater. This view has been indeed taken by Mr. Hopkins, who expressed his belief that sedimentary beds of considerable horizontal extent have rarely been completely destroyed. Furthermore, we must remember that, in so far as we have indicated three different cycles of deposition with their accompanying and characteristic forms of life, these animal forms are not restricted with any precision to these areas, and that organic

remains which, by some accident, have been destroyed upon one kind of bottom, may remain represented in another that was not subject to the same exigencies. As Prof. Verrill remarks, at the end of an enumeration of six or seven sorts of bottoms which carried distinctive faunas: "It must, however, be constantly borne in mind that very few kinds of animals are strictly confined to any one of these subdivisions, and that the majority are found in two, three or more of them, and often in equal abundance in several, though each species generally *prefers* one particular kind of locality. In other cases the habits vary at different seasons of the year, or at different hours of the day and night, and such species may be found in different situations according to the times when they are sought."

The animals living along rocky shores and clinging to the rocks themselves or dwelling in their crevices and amongst the sea-weeds that clothe them, are not so apt to be preserved as fossils, except as they die they are swept seaward and become buried in the muds or sands of the less exposed beaches and flats. The occupants of the sandy beaches are provided with organs and have developed habits which enable them to secure protection against the wear and violence of the waves and the alternating drying and wetting of the district they inhabit. They penetrate the sand deeply and secure immunity from the accidents of the surface in the pockets, burrows and tubes within which they can withdraw themselves. These protective habits render their preservation as fossils much more probable. The animals living in the muddy bottoms, whereon we may suppose a finer deposit settles, forming a tenacious and impalpable sediment or silt, are, in many cases, identical with those placed within the sandy areas, and immediately along the shores of a country the sandy and mud types of beach grade insensibly into each other so that a sandy beach can hardly be free from mud or a muddy margin of the land free from sand. And in this way the animal species found on one or the other accommodate themselves freely and easily to the vicissitudes and qualities of both. But the character of a mud bottom insures a better preservation of a shell as a fos-

sil, and many fragile and delicate organisms, such as the fossil hydrozoans, known as graptolites, are retained in the fine-grained slates (which have originally been mud layers) that would have scarcely survived comparison in the coarser and impressionable beds of sand. Such muddy layers may be entirely argillaceous or markedly siliceous, or they may be calcareous and formed at considerable depths, as in the case of the deep-sea ooze which assumes the character, as described by Sir C. Wyville Thompson, of a grayish, calcareous paste. These beds from this fine state of mechanical division are precisely adapted for keeping unbroken the tests, coverings and hard parts of the animals that are buried in them, and if sufficiently argillaceous to prevent crystallization, upon consolidating into stony strata retain their contents in a very beautiful and perfect condition.

The deeper zones of the sea nurture the coral growths, or receive from the pelagic life above them the unceasing contributions of dead shells, the cases of foraminifera, and the skeletons of aberrant crustacea, or form beds congenial to glassy sponges, submarine thickets of crinoids and fields of gorgonias. These sea-deposits, which are somewhat exempt from the mingling sediments of the shore, though, of course, only approximately, and more or less completely, according to the nature and distance of the neighboring coasts, as regards their fossiliferous character, form very perfect beds of deposition. The variety of animal life becomes here very great, and its fertility continually augments the rising sheets of animal precipitation. The pelagic life above these regions is constantly contributing its mineral contents to these beds, and the broken, half-dissolved shells of pteropods, with the tests and insoluble residue of foraminifera, form a calcareous commixture, in which whole shells, corals, crinoids, star-fishes, sea-urchins and the dust raining down from dead and decomposed swimming organisms, parts of fish, etc., become imbedded. The explorations of the Challenger showed that, according to Murray, the foraminifera of the open sea are subjected to solution in the carbonated sea-water, and that their argillaceous *ash*, so to speak, drops down and spreads upon the floor of the

ocean basin as a red or gray clay, while in places the siliceous parts of radiolarians also furnish a very considerable proportion of this mineral sediment, and the mass holding carbonic acid in solution has doubtless a solvent influence on many of the contained testaceous remains, and destroys their perfection as fossils. Upon elevation and consolidation into stony layers, the process of crystallization, started in the calcareous paste or jelly—which process partakes also of the nature of a hardening in a natural cement—produces sometimes a cementation of the parts, so that the fossils are coherent throughout with their matrix, and are extracted with difficulty, or, indeed, but obscurely detected at all. Centers of crystallization also form in the centers of the fossils themselves, by which all trace of organic structure is obliterated.

One of the most typical and important groups of fossils is the corals, and to discover the circumstances of their accumulation in the past we must look at the coral making portions of our globe to-day. Many of the deep sea corals are simple or single individuals, and are living in neighborhoods in the deep seas, while the great reef-making corals rising in coral banks to the surface of the water and prolonged by branching or acervuline growths are communal, and these coral colonies form the substantial basis of sea islands. They furnish the material which is heaped up in calcareous sand strata, making porous limestones, such as are seen in the Aeolian rocks of the Bermudas, or which, dissolved as a calcareous glue, unites the agglomerated fragments of beach shells into the Coquina beds of Florida. The coral colonies begin their growth at depths hardly exceeding 50 fathoms, though the Challenger explorations revealed coral life at depths of 1,300 fathoms. If they establish themselves in more shallow water at the customarily assumed limit of 20 fathoms, the sinking of the shores they skirt, according to the convenient hypothesis of Darwin and Dana, depresses the platforms from which they start to this depth or much more. The thermal conditions probably determine the depths at which reef-building corals can live, and it is a possible and probable circumstance that in varying positions and in other geological times, reef-making corals may

have begun their labors at depths much exceeding 20 or even 50 fathoms. The coral wall rises upward, and it bears in its midst and over its surface an extensive and variegated ocean life. First the corals of different genera massed together in contiguous groups and colums, then the fan corals (gorgonias) with *bryozoa*, *crinoids*, coralline sea-weeds and sponges, and finally numerous sea-worms (annelids) like *Serpula* complete the heterogeneous assemblage with an occasional mollusc or some sedentary crustacean. "All these things," to quote the expressive description of Thompson, "living and dying, are constantly yielding a fine powder of lime, which sinks down and compacts in the spaces among their roots; and every breaker of the eternal surf grinds down more material and packs it into every hollow and crevice capable of receiving and retaining it." In this dust the dying portions of the coral wall become entombed, and mingling with them the shattered or complete skeletons and remains of the associated fauna. Thus the whole is ready for fossilization; it is raised, or similar beds were raised, above the action of the ocean waves, becoming more and more bound together, more and more hardened and more dense. The solvent action of surface waters cement it together and converge through the interstices of the mass molecules of carbonate of lime which fill up the minute crevices, the microscopic pores, hastening the formation of a fossiliferous limestone. In these perfectly preserved masses, heads and nodules of coral are found retaining the most delicate details of structure, and with them fragments or complete examples of their associated guests and tenants. One of the most striking illustrations of an ancient fossil coral reef is that offered by the Falls of the Ohio at Louisville, Ky., where ledges of horizontal limestone form a low escarpment over which the river plunges. The formation is Devonian, and, while the softer parts of the stone have weathered away, the harder calcareous corals stand out in projecting groups, and in their commingled diversity of genera with bryozoal remains and the joints, stems and heads of crinoids, forms a complete reproduction of a modern coral reef. As to the condition of preservation in which the corals are found, Lyell has taken

occasion to call attention, in the collection of Dr. Clapp,[3] to the equal perfection of the "pores, foramina and minute microscopic structure" of the palaeozoic corals with those gathered from our present oceans, remarking that "no one but a zoologist would have been able to guess which set were of modern, and which of ancient, origin."

We may feel quite confident that in any study of our fossil-bearing strata we are generally contemplating beds that have not been abyssal in their origin. The remains of mollusca in the abundance usually present in our fossiliferous beds, cannot easily be regarded as indicative of very great depths of deposition. The Challenger expedition, while it revealed an unexpected fertility in the deep-sea life, also showed that molluscan life at great depths was scanty and unimportant. Sir C. Wyville Thompson summarizes the conclusions reached by saying that "the two great modern groups of the mollusca, the Lamellibranchiata and the Gastropoda, do not enter largely into the fauna of the deep sea. Species of both groups, usually small and apparently stunted, were widely, though sparsely, diffused." The character of many of the fossiliferous beds betrays readily enough the bathymetric relations they bore to the continent. The sandy grits, coarse conglomerate, the shales and slates, modified by the calcareous debris of shells and the argillaceous marls, are not deep-sea products. The pure limestones themselves cannot be regarded as having been formed at excessive depths since so much of the ancient life preserved in their fossils is irreconcilable with this view. Prof. A. Agassiz has indeed written (Dredgings of Three Cruises of the Blake): "Probably no invertebrates of a period older than the jura and chalk existed in the deep sea, or, if they did exist, they did not wander far from the continental shelf. Their distribution was then as to-day, mainly a question of food. The animals of those times lived upon the shelf, and, while they and their predecessors remained as fossils in the littoral beds of the earlier formations, their successors, belonging either to the same or to allied genera, passed over into the following period."

[3] Second Visit to the United States: Sir Chas. Lyell.

(*To be continued.*)